CMS at LLNL

DOE OHEP Visit

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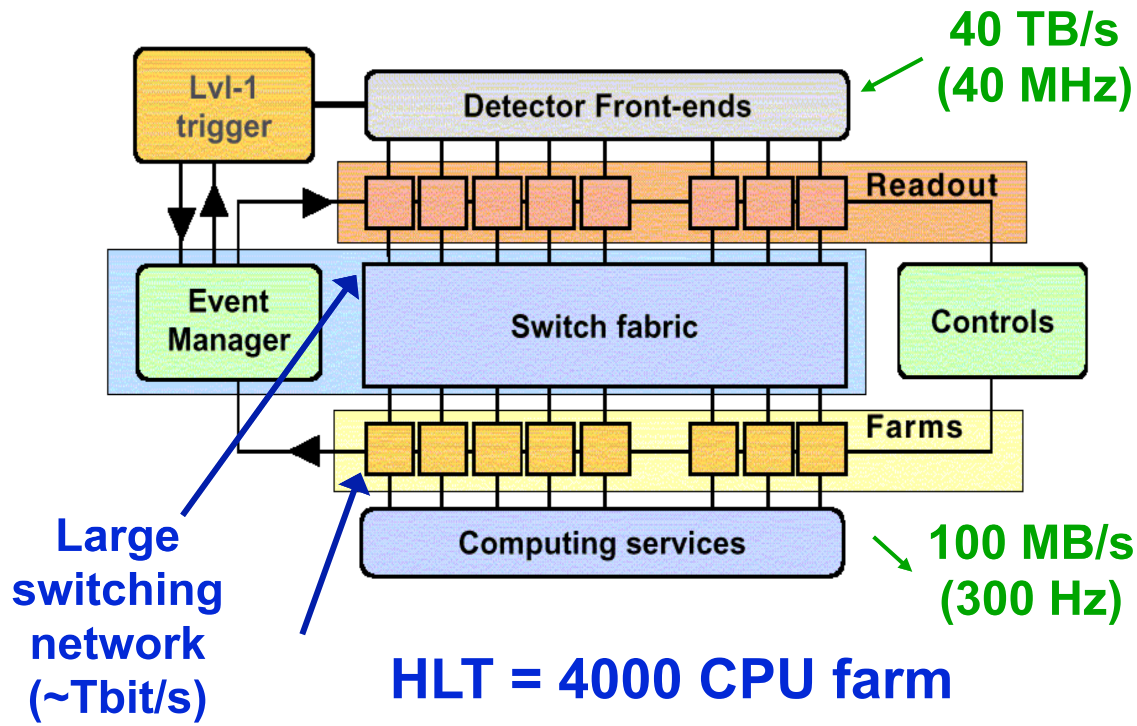
LLNL-PRES-471097

Getting CMS ready for first physics was a challenge

- **High Level Trigger (HLT) compute farm is final stage of CMS data acquisition, was completed just in time**
- **LLNL took lead on aspects of HLT completion:**
  - **Analysis of HLT performance: Uncovered critical timing issues resolved with detector experts**
  - **Developed configuration database: Required to track trigger changes while running (beam, detector, physics goals), essential for physics analysis**
- **Relocated 2 postdocs to CERN (Jonathan Hollar and Bryan Dahmes)**

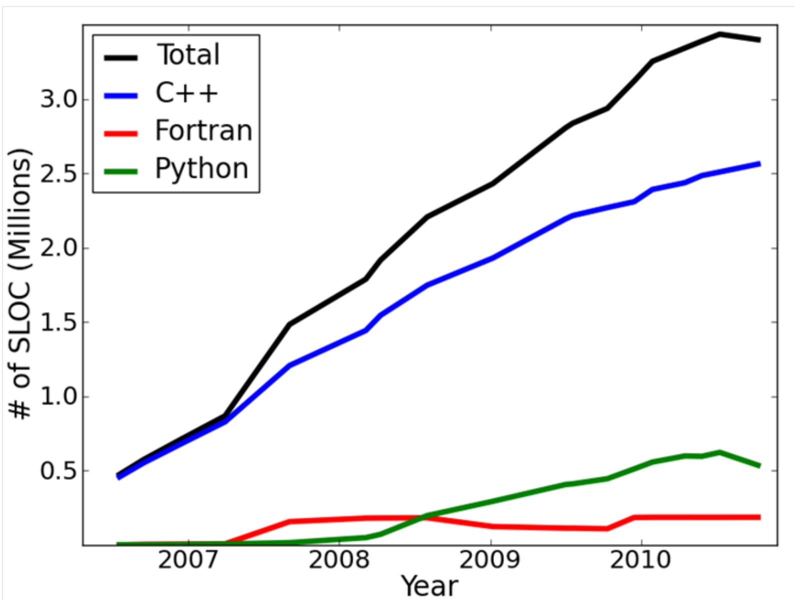


LLNL helped make CMS trigger a success (funded by LLNL)

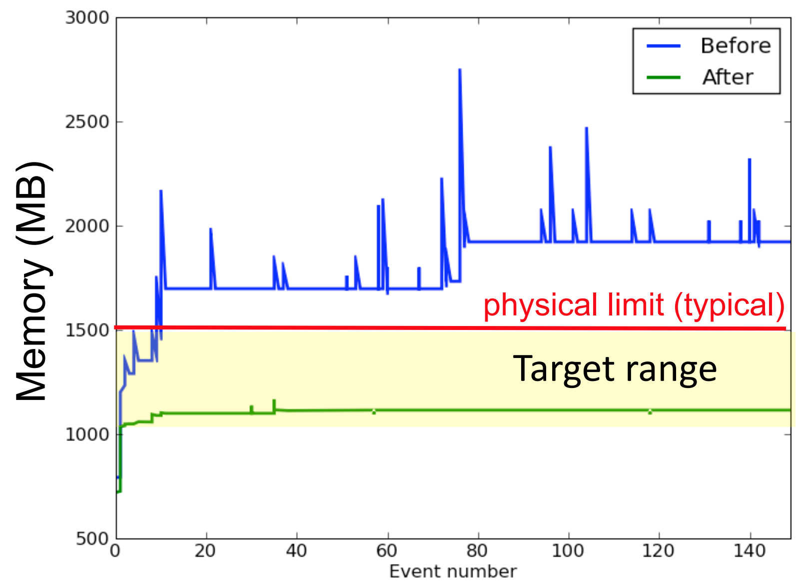
Keeping up with the data processing is difficult

- **David Lange appointed CMS Level 2 manager of software development tools + reconstruction group (capabilities developed for BABAR)**

Millions of lines of code, 200+ active developers



Solved particularly dramatic memory usage problem.

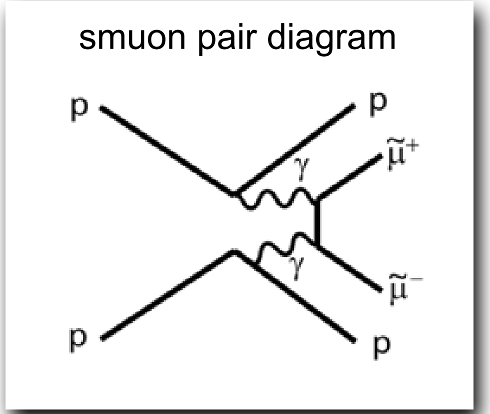


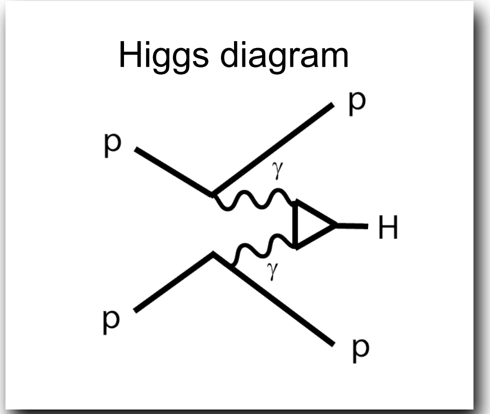
- **LLNL received OHEP Supplemental funds for multi-core computing R&D to keep up with LHC luminosity**

LLNL leadership of CMS reconstruction software a success (funded first by LLNL and later CMS project)

Backgrounds easily obscure new physics signals

- **LLNL pursuing innovative discovery channels via virtual $\gamma\gamma$ production (fundamentally new way to reject background)**



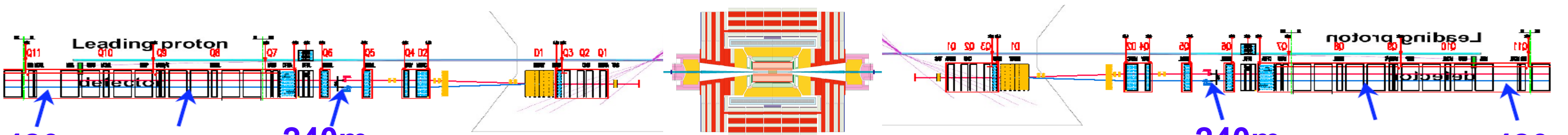


- **Protons remain intact**
- **No underlying event! Clear signature in CMS.**
- **Theoretically clean QED process.**
- **Cross sections are fb-pb.**

Leverages LLNL expertise from $\gamma\gamma$ collider physics

Proposed forward detectors enhance CMS physics reach

CMS



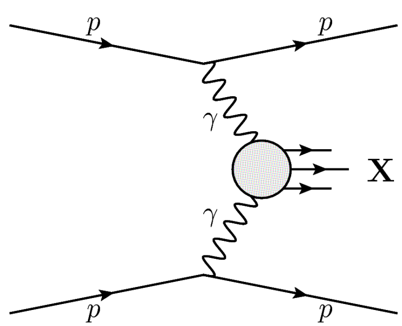
420m 240m

Forward detectors

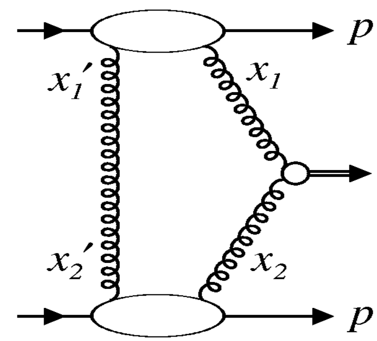
240m 420m

Forward detectors

- **Extra information by detecting scattered forward protons:**
  - **Interaction vertex point**
  - **Mass of the produced particle**
  - **Boost of the produced particles**
- **Enables SUSY, Higgs, QCD physics otherwise unattainable with CMS**



Central Exclusive Production (QED)



Central Exclusive Production (QCD)

CMS upgrade: small detectors have a big impact on physics

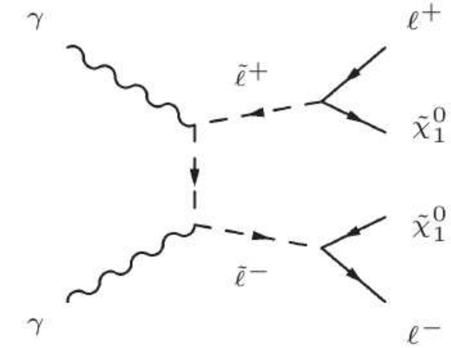
Slepton discovery possible with forward detectors

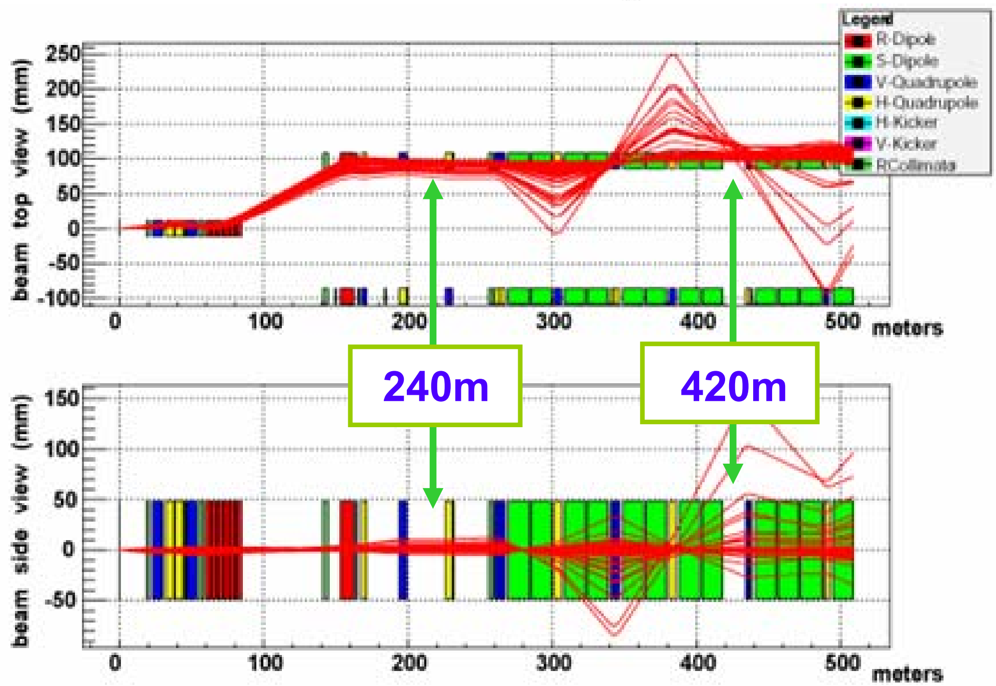
- **Current CMS can not detect sleptons directly**
- **LLNL di-smuon analysis**
  - Signal: isolated dimuon with two proton tags
  - Backgrounds separated via kinematics

    $p\mu\mu p$, $p\tau\tau p$

    $pWWp \rightarrow p\mu\nu\mu\nu p$
  - Slepton mass measured via edge in proton c.o.m.
  - CompHEP+HECTOR tracking through magnet optics

Central Exclusive Production (CEP)

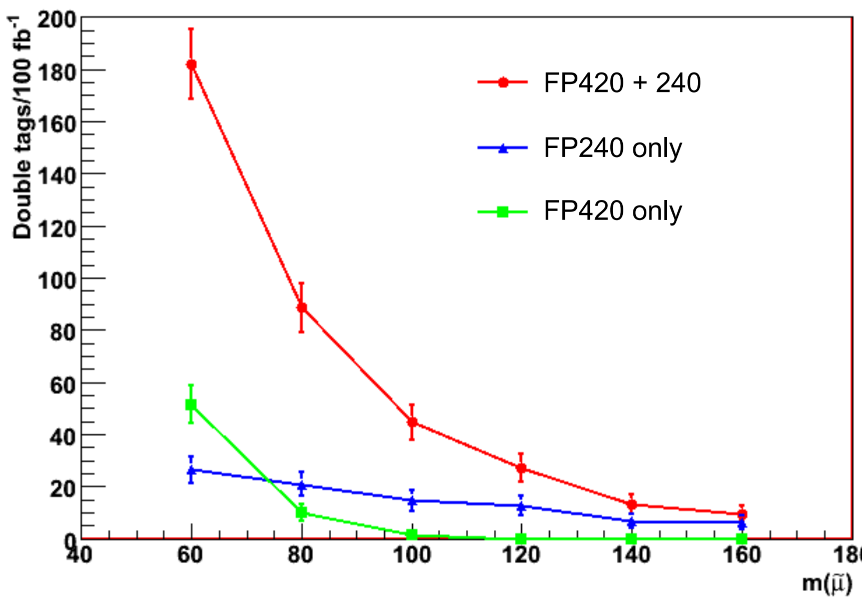




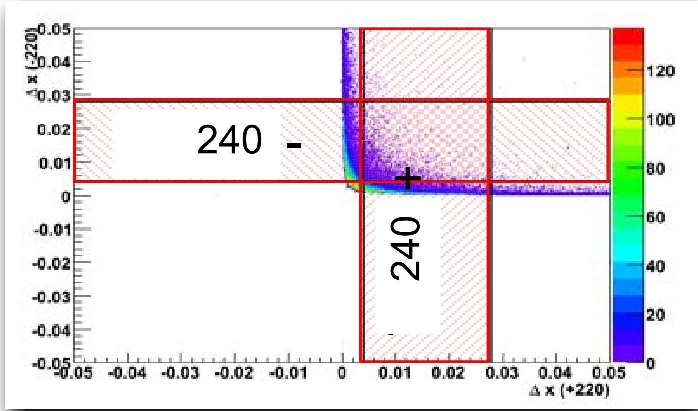
Can discover slepton and measure its mass

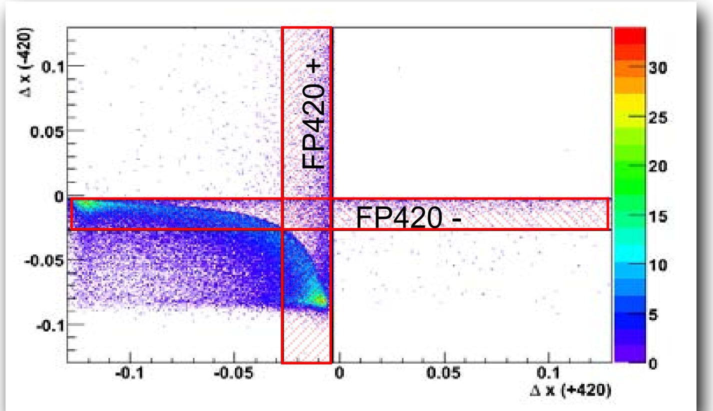
Slepton discovery possible with forward detectors

- **Proton tag efficiency**
  - Positive arm only 79%
  - Negative arm only 73%
  - Both 59%



proton displacement from beam

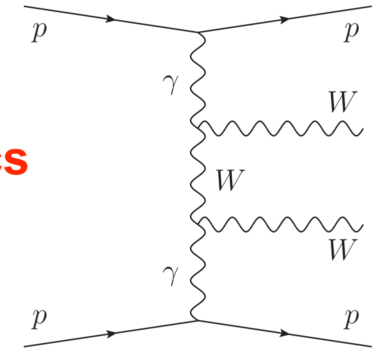


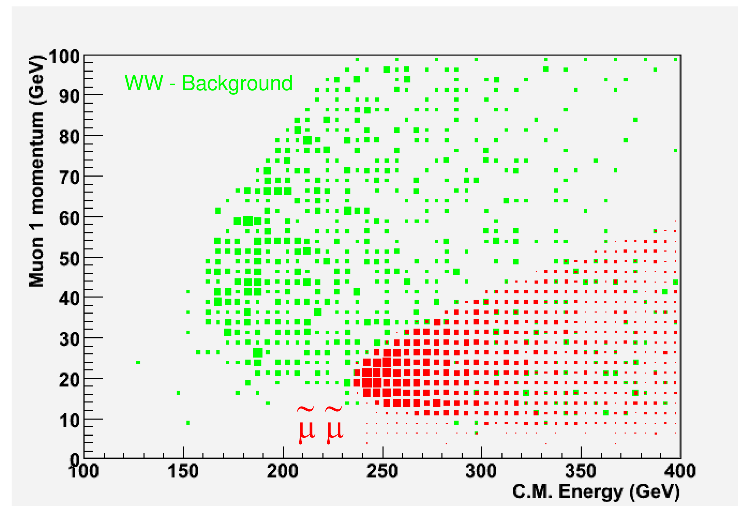


Can capture the signal, next step is to complete background studies

pWWp is both background and discovery channel

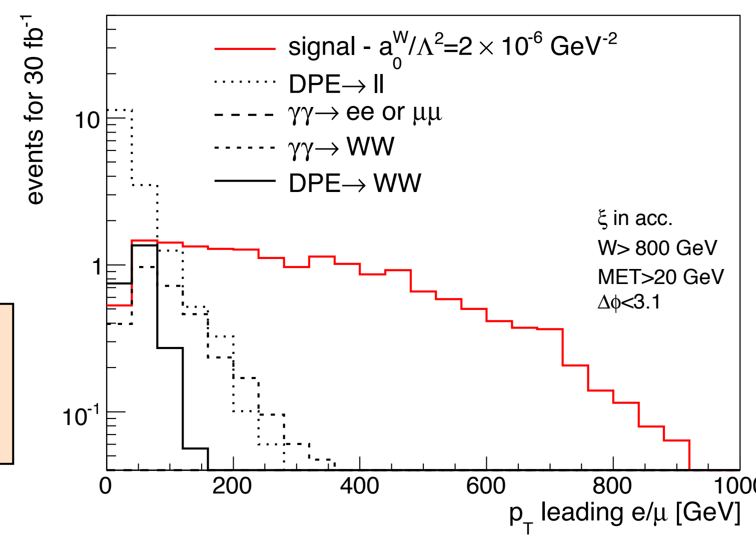
- Cleanly separated from slepton pairs using kinematics
- Can measure standard model rate with 5 fb^{-1}
- Anomalous quartic-boson coupling sensitive to Higgsless, very heavy Higgs, other beyond SM physics
- Standard WW measurement sensitive to triple-boson coupling which may not reveal the new physics
- Can improve quartic coupling measurement by factor ~10,000 over LEP, all the way down to Higgsless models





$$\mathcal{L}_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta) - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

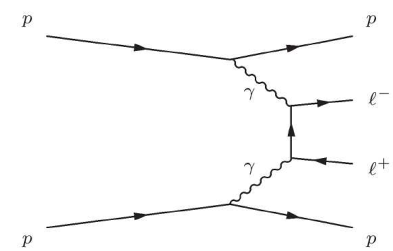


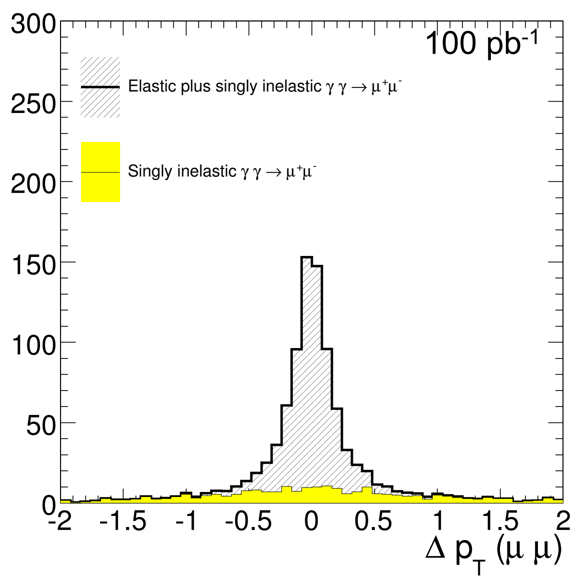
If LHC sees nothing, this can reveal new physics.
If LHC sees something, this can help explain it.

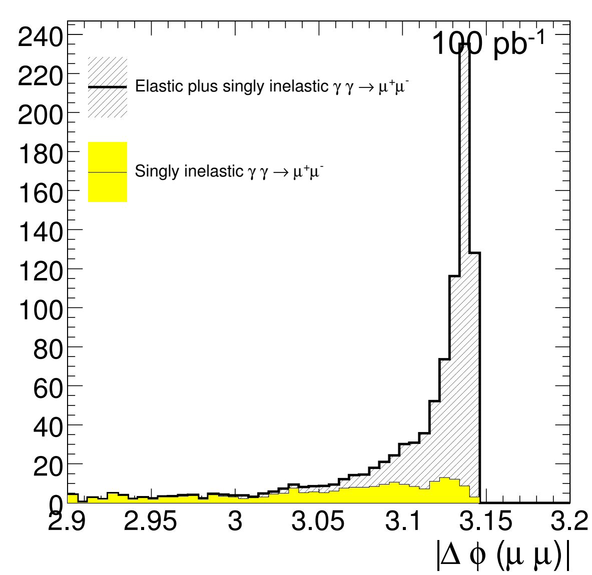
Dimuon analysis provides absolute luminosity measurement

- **Many CMS analysis are limited by lumi. uncertainty, e.g. W/Z cross section and SUSY search (due to W/Z+jet background)**
- **Precision Lumi. Tracker system not ready until 2013 and only measures relative luminosity**
- **Dimuon analysis can provide few % lumi measurement**
  - **7000 events/fb^{-1}**
  - **Must subtract contribution from single diffraction (if not proton tag)**
  - **Pileup will reduce the efficiency and ultimately limit the precision**

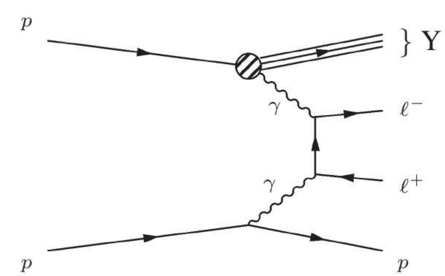
signal







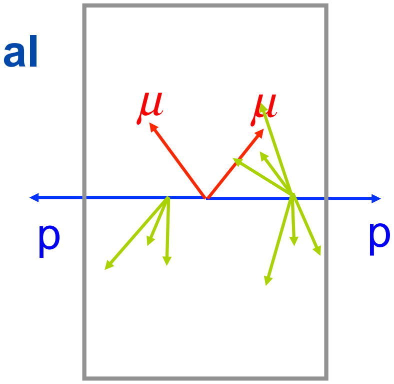
background (single diffraction)



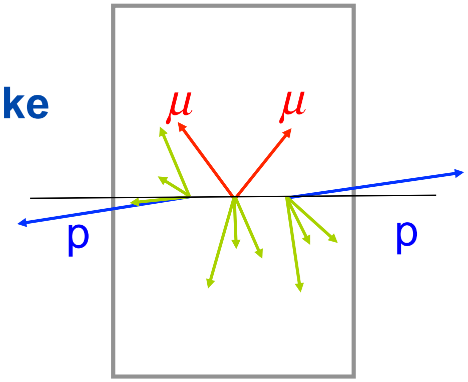
Valuable luminosity measurement, even before forward proton tags

Pileup becomes the problem, fast timing is a solution

di-smuon signal
with pileup



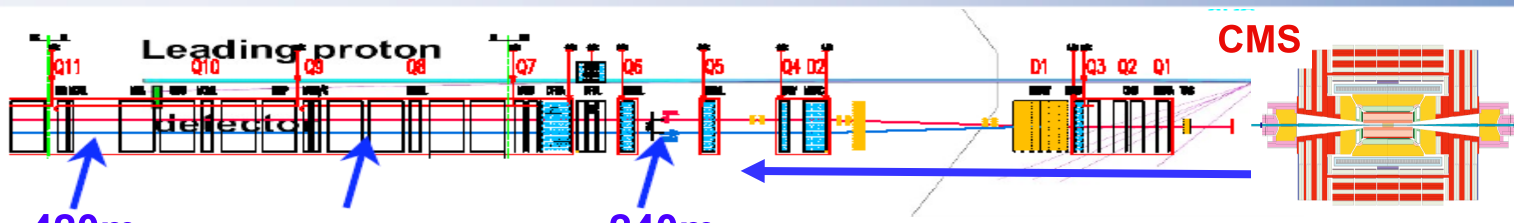
Drell-Yan di-muon
background with fake
double proton tag



- Eventually multiple-events per crossing makes “empty detector” cuts ineffective.
  - Vertexing within the event helps
  - Proton tag provides z position
- Triple coincidence involving two single-diffractions becomes a problem
  - 20ps resolution gives factor 24 rejection
- At max luminosity multiple proton tags per crossing becomes a problem
  - Reject with more precise and accurate (absolute) timing reference

Precision timing of protons is critical to forward detector upgrade

High Precision Spectrometer (HPS) is on track for CMS upgrade in 2013 shutdown

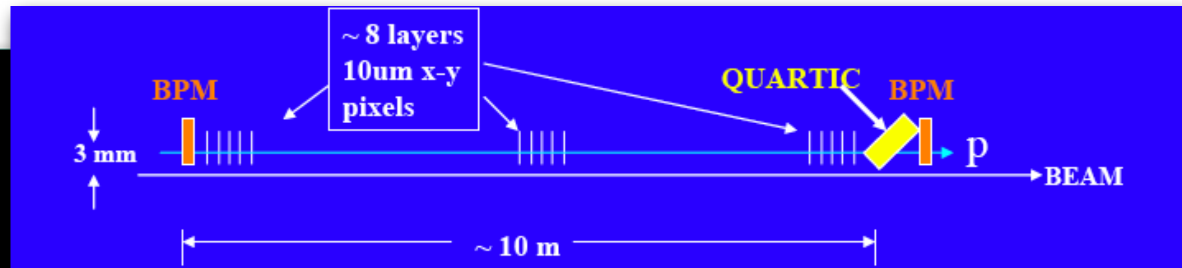


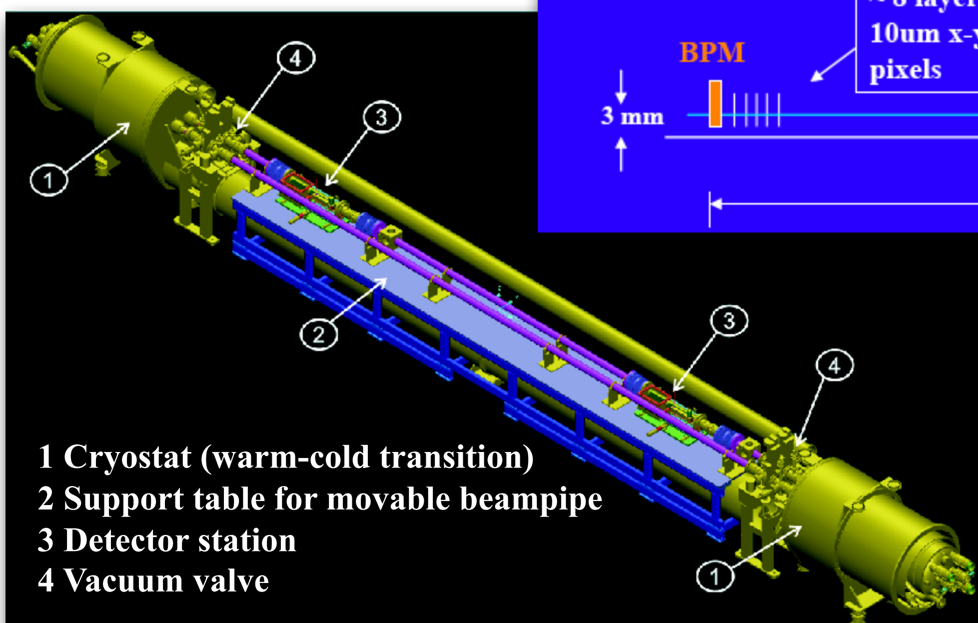
420m

Forward detectors

240m

Each station consists of: Silicon tracking and Cherenkov timing detectors





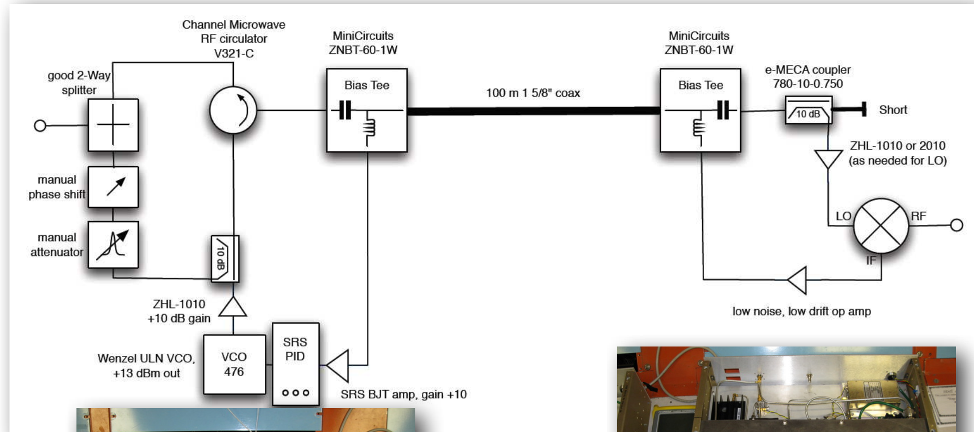
420m is in the cold section of the LHC
Modify LHC Arc Termination Modules
for cold-to-warm transition so detectors can
be at ~ room temperature

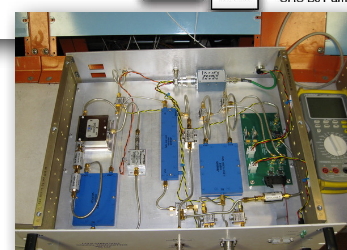
- Original plan: Detectors installed at 240m (420m) in 2012 (2016) shutdown

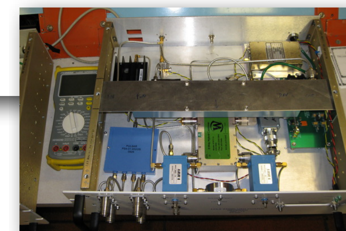
CMS approved R&D project, construction follows demonstrations

LLNL leads development of timing system for forward detectors (HPS)

- **Leverage system developed as trigger for LCLS detectors**
  - **RF cable with feedback to keep clocks at each end in sync**
- **Addressing CMS request for system demonstration:**
  - **LHC safety qualification**
  - **Signal stability for max length of 500 m**
  - **Design and prototype for LHC frequency**
  - **Time resolution with proton detector signals**
  - **Time resolution with CMS high-rate TDCs**

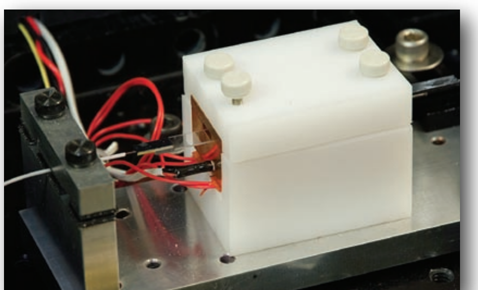


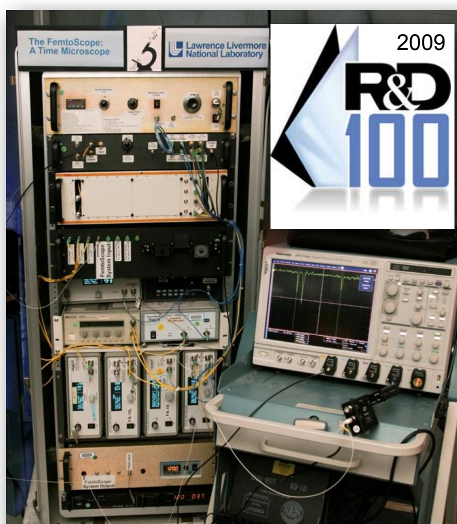


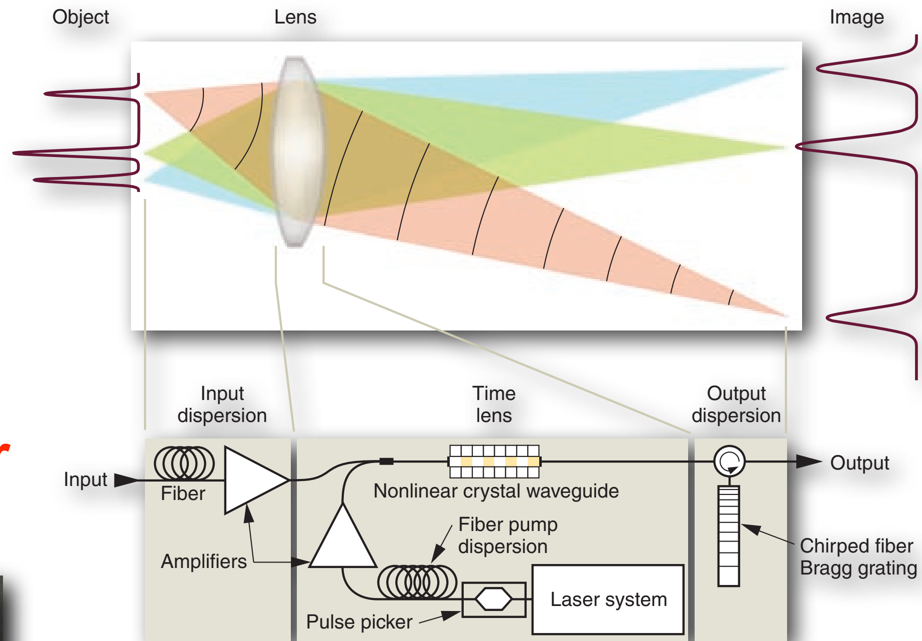


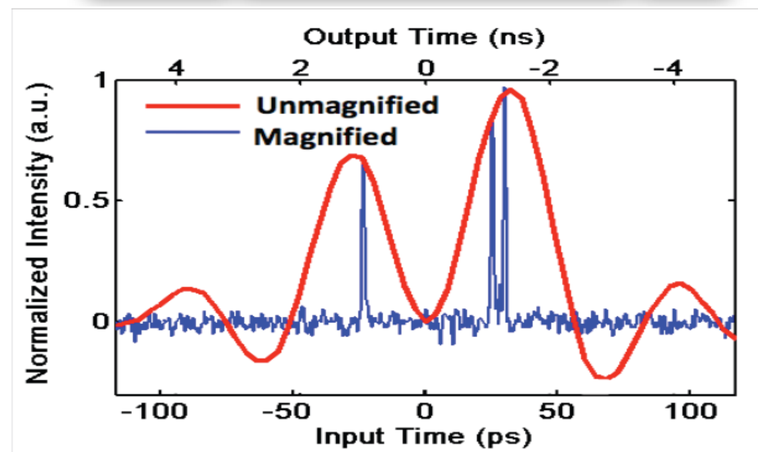
LLNL terahertz oscilloscope solves multiple proton detection problem for HPS

- **Optical time-stretcher permits 1 ps time resolution**
  - Chirped laser pump pulse on non-linear mixing crystal acts like a lens
  - Demonstrated factor of 100 time stretch and 0.75 ps resolution
- **CMS R&D plan: couple with proton detectors and design pump laser for LHC pulse structure**







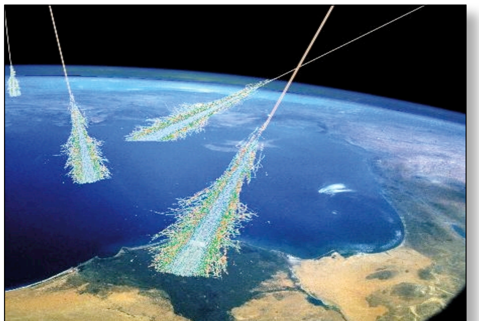


Unique LLNL technology developed from DARPA, NNSA, LDRD funding

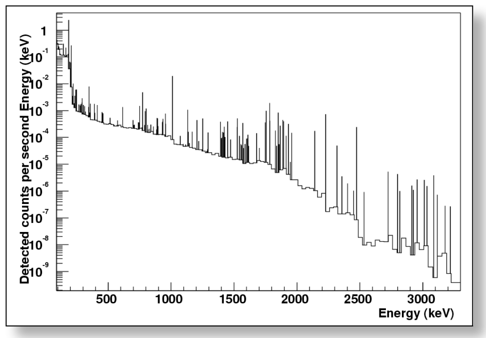
LLNL provides Geant4 capabilities for HEP

- **Open-source physics modules: built-in/add-on Geant4**
  - http://nuclear.llnl.gov
  - Official Geant4 collaborators

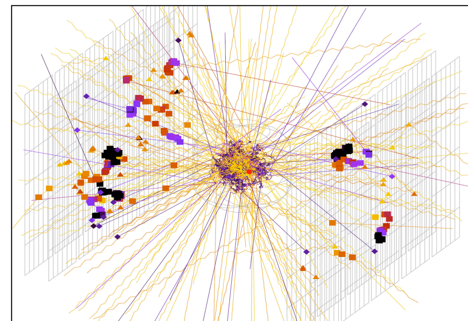
CRY: Cosmic-ray showers



RadSrc: Gamma-ray emission



Fission multiplicity



DHS funded

- **Next big thing: G4LEND (Low-energy Nuclear Physics from Data)**
  - Data-driven nuclear physics directly from nuclear evaluations
  - Collab. with SLAC, LLNL providing new format, interface, and all data
  - Enables background studies in LHC: low-energy neutrons, accel. background

NNSA + ARRA funded

Delivered by HEP physicists at LLNL, funded outside of OHEP

OHEP/LLNL partnership enhances the physics output of CMS

- **Ongoing contributions**
  - Discovery physics channels: sleptons and quartic boson coupling
  - Luminosity measurement from exclusive dimuons
  - Multi-core computing R&D and CMS reconstruction coordinator
  - Forward proton detector reference timing system for physics upgrade
  - Terahertz oscilloscope technology
  - Geant4 simulation capabilities
- **Joined CMS in 2005**
  - 2 post-docs
  - 3 senior scientists
  - Software-development tools coordinator
  - High-level trigger commissioning